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New Sources of Resistance to Stem Rust and Leaf Rust in Foreign Varieties of Common Wheat[1]

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SUMMARY

Differences in reaction of wheat varieties to the cereal rusts have been recognized since as early as 1841, but breeding for resistance as a means of controlling rust does not appear to have been suggested until about 50 years later.

The stem rust-resistant varieties of common wheat first grown in the United States lacked sufficient resistance to keep down losses in years of heavy epidemics. There is considerable evidence of the increase of physiologic races of the disease organism to which the so-called resistant varieties were susceptible. The limitations in any single variety demonstrate the importance of finding additional factors for resistance.

In the experiments reported here 1,639 varieties and strains of foreign wheats were tested under field conditions. Of these, 43 common wheats gave resistant reactions and lower percentage readings of stem rust than the Kota check variety. Thirteen of the 43 also were highly resistant to leaf rust.

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[1] Cooperative investigations of the United States Department of Agriculture and the Texas Agricultural Experiment Station.

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All wheat-producing continents have representatives among the 43 rust-resistant varieties, which shows that resistance in the common wheats, although of rare occurrence, has wide geographic distribution.

Several distinct types of resistance to stem rust appear to be available, which suggests that several different genetic factors may be involved. The possible utilization of the various types of resistance in wheat breeding is discussed.

Several of the rust-resistant varieties have other desirable characters that may make them of considerable value as parental material in breeding for qualities other than rust resistance.

REVIEW OF LITERATURE

Differences in the reaction of wheat varieties to the various fungus diseases known as rusts were reported by Henslow (*13*)[2] of England as early as 1841. About 50 years later Farrer in a report to the Committee on Rust in Wheat Conference (*26*, *27*) of Australia made the first serious suggestion of the possibility of controlling these diseases through breeding for resistance. Today, after the lapse of another half century, the breeding of wheat for resistance to the rusts and various other diseases is under way in all of the major wheat-producing regions of the world.

It has been widely recognized for a long time that certain varieties of einkorn (*Triticum monococcum* L.), emmer (*T. dicoccum* Schrank), durum (*T. durum* Desf.), and poulard (*T. turgidum* L.) showed marked resistance to one or more of the rusts and that certain varieties of common wheat (*T. aestivum* L. (*T. vulgare* Vill.) Host) were moderately resistant to leaf rust (*Puccinia triticina* Eriks.) or stripe rust (*P. glumarum* (Schm.) Eriks. and E. Henn.). Prior to 1916, however, a marked degree of resistance to stem rust (*P. graminis tritici* Eriks. and E. Henn.) was not known to exist in any of the varieties of common wheat grown in the United States.

In 1916 Melchers and Parker (*21*, *22*, *23*) observed what appeared to be a high degree of resistance to both stem rust and leaf rust in three pure-line strains of Crimean winter wheat. One of these was later introduced under the name of Kanred (C. I. 5146),[3] and within a few years became widely grown in the winter-wheat belt of the United States. It soon proved to be susceptible to certain physiologic races of both stem rust and leaf rust, and in recent years Kanred has been largely displaced by other varieties.

A variety of hard red spring wheat of Russian origin (Kota) was reported by Waldron and Clark (*29*) to be moderately resistant to stem rust in North Dakota in 1917 and 1918, and in later years by Clark and Waldron (*6*). This wheat has been grown commercially in the worst rust sections of Minnesota, North Dakota, and South Dakota. Like the Kanred variety, it is susceptible to several races of stem rust and leaf rust, and in the severe epidemic of 1927 suffered considerable injury. A few years later, Ceres wheat, which derived its stem rust resistance from the Kota parent, was introduced and widely grown, but it also succumbed to stem rust in the destructive epidemic of 1935.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 15.

[3] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

Another variety of spring wheat (Webster) was discovered in 1917 to be resistant to stem rust and leaf rust by McFadden (*17*). The writer also noted that the Webster type of resistance to stem rust is associated with a long incubation period of the pathogen, so that more than one or two generations of the disease seldom develop between heading and ripening of the host plant. Later studies by Stakman, Levine, and Griffee (*28*) showed this wheat to be at least moderately resistant in the seedling stage to all the 19 physiologic races of stem rust to which they subjected it. Nevertheless, later studies under field conditions demonstrated that the Webster type of resistance to stem rust is not generally effective against the disease except under semiarid conditions.

More recently, Peterson and others (*25*) and Newton and coworkers (*24*) reported a high degree of seedling resistance to many physiologic races of stem rust in the Canadian variety McMurachy and several other varieties of wheat from Kenya, East Africa. Some of these Kenya varieties had previously been reported by Burton (*3*) and Macindoe (*16*) as being rust resistant in Kenya and New South Wales, respectively.

Carleton (*4*) appears to have been the first to suggest the possibility of transferring rust resistance from the tetraploid wheats (durum and emmer) to common wheat through cross-breeding, a line of work that has resulted in marked progress in recent years. In following Carleton's suggestion, Hayes, Parker, and Kurtzweil (*12*), in cooperative experiments with the Bureau of Plant Industry conducted at the Minnesota Agricultural Experiment Station, succeeded in transferring certain factors for moderate resistance to stem rust from Iumillo durum to the *vulgare* wheats. One of the rust-resistant *vulgare* segregates (Marquillo) from this cross later became a commercial variety in the Red River Valley of Minnesota and North Dakota. Marquillo was soon supplanted by Thatcher (*11*), which was derived in part from the same cross. Thatcher has greater field resistance to stem rust than Marquillo but is highly susceptible to leaf rust. It at first was very popular and soon became the most widely grown variety in the spring wheat area of the United States and Canada, but its susceptibility to leaf rust and other diseases has in recent years caused it to be largely supplanted by other varieties in the United States.

In 1920 McFadden (*18*) in South Dakota succeeded in isolating *vulgare* strains highly resistant to both stem rust and leaf rust and several other diseases from a cross between Marquis and Yaroslav emmer. Two of these segregates (Hope and H–44) were practically immune to stem rust in the mature plant stage. Although neither of these was ever extensively grown commercially, largely because of their susceptibility to heat and drought, they have been widely used as parental material and have given rise to a dozen or more rust-resistant varieties that are now grown extensively in the spring wheat belt of the United States and Canada.

NEED FOR ADDITIONAL FACTORS FOR RESISTANCE

That many physiologic races of both stem rust and leaf rust of wheat can be identified by their reactions on seedlings of selected varieties has been amply demonstrated by numerous experiments, briefly reviewed by Ausemus (*2*). From experience with such varieties as

Kanred, Kota, and Ceres, it has also been clearly demonstrated under commercial field conditions that varieties that sometimes appear at first to have satisfactory field resistance may later succumb to the disease as a result of changes in the prevalence of physiologic races.

In experiments summarized by Ausemus (*2*), evidence has also been found that there are several distinct types of resistance to stem rust. It is known also that resistance to stem rust may be due to a number of different genetic factors, which may or may not belong to the same allelomorphic series. Also these factors may differ in the symptoms they produce. For instance, the principal factors for resistance occurring in Kota, Kanred, Webster, and Hope appear to be all different, and it is possible that all these factors, as well as others that may be found, ultimately can be used to good advantage in one way or another in breeding for resistance.

Clark and Humphrey (*5*) demonstrated that under field conditions two factors for mature plant resistance to stem rust are present in Hope wheat. One of these is dominant and the other recessive in its inheritance. It at first appeared that the dominant factor was effective against all physiologic races of stem rust under all environmental conditions. Later studies by Hart and Zaleski (*10*), however, demonstrated that the normal effects of the dominant factor in Hope wheat may break down under artificial conditions in the greenhouse. Abbott (*1*) also reported that Hope wheat developed considerable stem rust under field conditions in the foggy areas of Peru, and his suggestion that this might be due to the presence of an especially virulent physiologic race of the disease in that country was later verified by Garcia-Rada and others (*7*). More recently, Loegering and Stakman (*15*) announced the discovery of an especially virulent race of stem rust in the United States that is capable of fairly normal development on mature plants of certain Hope derivatives that had previously been highly resistant in the field. Moreover, as pointed out by McFadden (*19*), the dominant factor for resistance to stem rust in Hope and H–44 appears to be very closely linked with susceptibility to drought and heat.

McFadden (*20*) also reported that the dominant factor for resistance is associated with a peculiar type of pigmented necrosis of internodes, peduncles, rachises, and glumes as a result of infection by stem rust, and that such necrosis may become severe when rust inoculum of certain races is abundant previous to the heading of the plants. Hagborg (*9*) and Johnson and Hagborg (*14*) have presented evidence that this type of necrosis, or a similar discoloration, may also result when wheats carrying the Hope dominant factor are exposed to certain environmental conditions. Furthermore, from the studies of Goulden (*8*) and McFadden (*18*), wheats may develop considerable rust in early stages of growth, unless the plants having this dominant factor for resistance also carry factors for seedling resistance. It it obvious, therefore, that the most effective use of the Hope dominant factor for breeding resistant wheats is limited by environment and may give more satisfactory results when combined with other factors for resistance. It is especially apparent that this dominant factor alone is not entirely suitable for semiarid conditions or for conditions in the South, where the climate is favorable for rust development during the early stages of growth.

Although stem rust is not often a limiting factor in the drier parts of the Great Plains, there is occasionally a year in which the disease reaches epidemic proportions. Such was the case in 1938, when the disease caused serious losses in the Rio Grande Valley of Texas early in March and swept northward along the western edge of the entire Great Plains area. The growing of rust-immune varieties in the more humid sections of the country to the south and east of the Great Plains should practically eliminate the inoculum that is responsible for starting these occasional epidemics. If the inoculum derived from other areas is to be eliminated entirely, however, the varieties of wheat grown in those areas must be immune to all physiologic races of rust both in early and in late stages of growth. It would therefore be desirable to have factors that give resistance to all physiologic races of stem rust at all stages in the life of the host; or if this is not possible, to find factors that give resistance to all races in the early stages of growth of the host to combine with the dominant factor for mature plant resistance derived from Hope and H–44. In view of the facts here enumerated, the importance of further search for additional genes for resistance is obvious.

THE PRESENT INVESTIGATIONS

The fortuitous discovery of resistance to stem rust in the common wheat varieties, Kota, Webster, and the three Crimean wheats, after they had been grown experimentally for several years, suggested that a concerted study of the wheat varieties of the world would lead to the discovery of many other varieties that would carry additional factors for resistance to the cereal rusts. These varieties might be of value as parental material in the program to control rusts through breeding. The exceptionally favorable climatic conditions for the development of the cereal rusts at College Station, Tex., suggested that location as a logical place to undertake an extensive study under natural field conditions. Accordingly, one of the first experiments conducted, following the initiation of cooperative cereal rust investigations at College Station in the fall of 1935, was the testing of foreign wheat introductions for reaction to both stem rust and leaf rust under field conditions.

MATERIAL AND METHODS

In the fall of 1936, through the courtesy of B. B. Bayles, of the Division of Cereal Crops and Diseases, 634 varieties and selections of foreign wheats recently introduced by the Division of Plant Exploration and Introduction were assembled and sent to College Station, Tex., for inclusion in these studies. The testing of several hundred additional wheats later assembled has brought the total number tested to 1,639. These have included nearly all the species and subspecies of wheat.

It is believed that they include all introductions with P. I. numbers between 58685 and 131401,[4] inclusive, and numerous varieties with no P. I. numbers.

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[4] Accession numbers of the Division of Plant Exploration and Introduction.

The first, or preliminary, tests were conducted at College Station during the period 1937–39. Each strain was sown in single 7-foot rows spaced 1 foot apart. Those varieties that appeared to be resistant to stem rust were sown in rod rows in the fall of 1939 at College Station, Angelton, and Weslaco, Tex. A few well-known resistant and susceptible varieties were included as checks. These consisted of the stem rust-susceptible varieties, Marquis and Gasta, and several stem rust-resistant varieties including Vernal emmer, Iumillo durum, Thatcher, Hope, and two selections from Kota × Webster designated as H151 and H231.

Usually after a variety had been grown for 1 year in the preliminary nursery, it was discarded unless it showed some evidence of resistance to stem rust. If evidence of resistance was found the variety so characterized was continued for further observations.

Stem rust readings were taken when the plants were in the hard-dough stage of maturity, and the leaf rust reading usually 1 to 2 weeks earlier. The percentages of infection for both rusts were determined in accordance with the "Scale of Estimating Rusts," in general use by the Department's Division of Cereal Crops and Diseases.

Although climatic conditions at College Station usually are very favorable for heavy infection by both stem rust and leaf rust, the distribution of stem rust inoculum often is very uneven until very late in the season. In order to insure a better distribution of inoculum, the testing nurseries were surrounded by a border of two rows of susceptible material consisting of a mixture of Gasta and Hard Federation wheats. Single rows of the same material were planted in every other alley throughout the nursery.

As soon as the varieties in the rust spreader rows started jointing, inoculum was collected from all the infection centers in the nursery. A water suspension consisting of a mixture of urediospores from all centers was then used to inoculate plants hypodermically in the rust spreader rows at intervals of about 10 feet. This was usually done at some time in March, or 2 weeks to a month before the majority of the wheat varieties came into head. Infection took place within 10 to 15 days following inoculation. In spite of these precautionary measures, however, certain early maturing varieties in both 1938 and 1939 matured ahead of the general stem rust epidemics of those years, and consequently matured too early to obtain reliable notes on their reactions to stem rust.

EXPERIMENTAL RESULTS

REACTIONS TO STEM RUST

For the sake of brevity data are not reported for varieties other than checks that proved to be highly susceptible to stem rust. The percentage of stem rust and the type of reaction of the varieties grown at College Station for the 4 years 1937–40 and at Angleton and Weslaco in 1940, the 5-station-year average percentage, and the rank for each variety are given in table 1. Since only a few varieties were grown in 1937, data for that year are not included in the average percentages of infection.

The physiologic races of stem rust present at College Station each year were identified by Stakman and Loegering, at University Farm, St. Paul, Minn., from collections taken by the writer from all natural infection centers in or near the nursery as soon as they were found and from later collections taken from several varieties in the nursery. Usually only one race was isolated from each infection center. Physiologic races 24, 38, and 56 were identified in 1937; 1, 17, 49, and 50 in 1938; 46 and 56 in 1939; and 17, 38, and 56 in 1940; also 15, 17, and 56 from collections made at Weslaco in 1940.

Although at one time considered resistant to stem rust, the Kota variety, used as a standard check in these tests, showed relatively high percentage readings and gave a susceptible pustule type of reaction every year at all points where grown. This may be attributed to the prevalence of such physiologic races as 56, to which Kota is susceptible. Despite the susceptible pustule type some field resistance is obvious, since the percentage readings were consistently lower than for Marquis.

Of the 1,639 varieties of all species tested, the 43 belonging to the common wheat group that are listed in table 1 were found to have lower average stem rust readings under field conditions than the Kota check. Among these are varieties from Argentina, Uruguay, Paraguay, and Brazil, in South America; from the Union of Soviet Socialist Republics, Italy, Portugal, Spain, Switzerland, and Greece, in Europe; from Kenya Colony, in Africa; from New South Wales, in Australia; and from Canada and the United States, in North America. Webster wheat, one of the parents of Kota × Webster strains, was imported from the Russian Turkestan (Turkmen S. S. R.) section of Asia. It will be seen, therefore, that all the wheat-growing continents have representatives among these resistant *vulgare* wheats. Evidently resistance to stem rust in the common wheats, although of rare occurrence, has a wide geographic distribution.

The only varieties that gave zero readings at all points for all years grown were two of the check varieties, Hope and Iumillo durum. Three varieties (P. I. Nos. 117768, 117641, and 117526) gave lower average readings than the Vernal emmer check. Sixteen varieties gave lower average readings than the Thatcher check, while all varieties except Vencedor gave lower readings than the Kota × Webster and Gasta checks. Gasta, although completely susceptible, escaped heavy infection in three of the five tests as a result of its early maturity.

The resistant varieties differed considerably, not only in the degree of resistance but also in the type of reaction and in the stability of their reactions under the different environmental conditions prevailing from year to year.

Such varieties as Uruguay 386, Argentine K40, and most of the varieties from Kenya were practically rust-free, both early and late in the season at all stations in all years. Other varieties, as Vencedor and P. I. 116222, showed indications of resistance in certain years, but gave susceptible reactions in others.

TABLE 1.—*Reaction to stem rust of 43 foreign varieties of vulgare wheat that gave lower average rust readings than the standard Kota check variety*

[R−=Very small pustules; R=small; R+=medium; P=a type of high resistance associated with brown pigmentation; S=susceptible (large confluent pustules)]

Variety or strain	P. I. No.	Other designation	Stem rust infection											Rank for resistance
			College Station								Angleton	Weslaco	Average percentage 1938-40	
			1937		1938		1939		1940		1940	1940		
			Percent	Reaction	Percent	Reaction	Percent	Reaction	Percent	Reaction	Percent	Percent		
Hope (check)		C. I. 8178	0	P	0	P	0	P	0	P	0	0	0	1
Inmillo (check)		C. I. 1736	0		0		0		0		0	0	0	1
Kenya	117526	C9968			0		0		[1]	R	0	0	.1	2
Do	117768, 118896	C9906			[1]	R	0		0		0	0	.1	2
Kenya × Gular	117641	4913			[1]	R	0		0		0	0	.1	2
Kenya	117527, 117770	C10854			[1]	R	0		[1]	R	0	0	.2	3
Do	117528	C10856			[1]	R	0		[1]	R	0	0	.2	3
Do	117529, 117774	C10863			[1]	R	0		[1]	R	0	0	.2	3
Do	117767	C9724			[1]	R	0		[1]	R	0	0	.2	3
Kenya × Gular	117612, 117791	5935			[1]	R	0		0		0	[1]	.2	3
Vernal emmer (check)		C. I. 2975	0	P	[1]	P	[1]	P	0	P	0	0	.2	3
Kenya crossbred	103539	C6010	5	R+	[1]	R	[1]	R	[1]	R	0	0	.3	4
Argentine K40	116297, 117492	C9658			[1]	R	[1]	R	[1]	R	0	[1]	.4	5
Uruguay 392	116328, 117501	C10837			[1]	R	[1]	R	[1]	R	0	[1]	.4	5
Kenya	117769	C9967			5	R	0		0		0	0	1.0	6
Kenya crossbred	103540	C6012	0		[1]	R	0		5	R	0	0	1.1	7
Kenya	117771, 118900	C10857			[1]	R	0		0-10		0	0	1.1	7
McMurachy selection		R L1313			5	R	0		5	R	0	0	2.0	8
Uruguay	116234, 116327, 117501	C10835			5	R	0		5	R	0	[1]	2.1	9
Thatcher (check)		C. I. 10003	[1]	R	5	R	[1]	R	5	R	0	[1]	2.2	10
Uruguay 386	116326, 117503	C10838			10	R	[1]	R	[1]	R	0	[1]	2.3	11
Trigo Rojo	93337		15	R−	5	R	5	R	5	R	0	[1]	3.1	12
Kenya	118901	C10862			[1]	R	0		0		0	15	3.1	12
Renacimiento		C. I. 12002	10	R−	5	R	5	R	5	R	0	[1]	3.1	12
Kenya	92475	K. 2R.5 (L. 2)	25	R−	15	R	0		[1]	R	0	[1]	3.2	13
Surpresa	103833, 106505		5	R+	[1]	R	5	R	10	R	0	[1]	3.2	13
M 12-32	103831		[1]	R+	10	R	5	R	5	R	0	[1]	4.1	14
Fronteira	103832, 106503	C. I. 12019	5	R+	10	R	5	R	5	R	0	[1]	4.1	14
Argentine K33	116222, 116298, 117491	C9655			[1]	R	10	S	10	R	0	[1]	4.2	15
Portugal 90	116231	C7921			15	R	5	[2] R	[1]	R	0	[1]	4.2	15
Minor	117496	C9142			15	R	[1]	R	5	R	0	[1]	4.2	15

Frondoso	106504	C. I. 12078	25	R−	10	R	5	R	5	R	0	5	5.0	16
Kenya × Florence × Dundee	117786	5130			(1)	R	0		5	R	0	25	6.1	17
Portugal 65	116230	C7897			25	R	5	[2] R	(1)	R	0	(1)	6.2	18
Kenya	118904	C10866			10	R	10	R	15	R	0	0	7.0	19
Do	118903	C10865			0		15	[3] S	25	R	0	0	8.0	20
Argentine	116223, 116299, 117490	C9656			(1)	R	0		15	R	0	25	8.1	21
Greek 18	116226, 116301, 117495, 117606, 117755.	C7142			10	R	10	R	25	R	0	(1)	9.1	22
Bladette de Besplas	103528	C6148	50	R−	25	R	10	R	10	R	0	5	10.0	23
Greek	116227, 116300, 117494, 117605, 117754.	C7135			25	R	5	[2] R	15	R	0	5	10.0	23
Kenya × Florence × Dundee	117782	264D			(1)	R	0		30	R	0	25	11.1	24
El Milagro	116015				5	R	(1)	R	(1)	R	0	50	11.2	25
San Martin	104137	SF12706	25	R−	25	R	10	R	25	R	0	10	14.0	26
Gelou		C. I. 12001	10	R−	30	R	15	R	15	R	0	15	15.0	27
Triunfo	104138	SF12709	25	R−	25	R	10	R	30	R	0	15	16.0	28
Varonne	116236, 116330, 117505	C6146			10	R	15	R	30	R	0	25	16.0	28
Kota × Webster (check)		H231	5	R	10	R	5	R	40	R	25	15	19.0	29
Do		H151	5	R	15	R	5	R	50	R	25	25	24.0	30
Gasta (check)		C. I. 11398			5		50		15		(1)	75	29.1	31
Vencedor	104139, 117506	SF12708			10	R	15	S	75	S	5	75	36.0	32
Kota (check)		C. I. 5878			30	S	25	S	75	S	50	50	46.0	33
Marquis (check)		C. I. 3641		R	100	S	90	S	90	S	75	80	87.0	34

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[1] Trace; estimated at 0.5 in computing averages.

[2] Linear pustules.

[3] Large pustules on sheath.

Other varieties, as McMurachy, Thatcher, and several of the Kenya varieties, were consistently rust-free early in the season, but in some years developed a trace or more of small, distinctly isolated pustules shortly before they matured, showing that complete immunity in the early stages of growth may occasionally be lost shortly before maturity. The cause of this loss of immunity is not evident from these studies. Investigations recently reported by Newton and others (*24*), however, suggest that this may be due to the higher temperatures encountered by the plants during the later stages of growth. At any rate, it is evident that there is a tendency under certain conditions for such varieties to lose their extreme resistance shortly before ripening, while the resistance of such varieties as Hope and H–44 usually increases in the later stages of growth.

Certain other varieties, not listed in table 1, although showing a low percentage reading early in the season, nevertheless gave a completely susceptible reaction and later in the season developed a high percentage reading. Other varieties, as Hope, remained entirely free from external pustules but showed characteristic discolored areas, indicating that infection had taken place. Certain of the Hope wheat derivatives, not listed in the table, were completely susceptible early in the season but later became highly resistant, the early infection drying up and becoming surrounded by melanistic necrotic areas.

The indication that some of these distinct types of resistant reactions may be used to advantage in breeding for resistance under different environmental conditions or may be combined so as to give resistance under a wide range of conditions seems worthy of further investigation.

In addition to the varieties listed in table 1, many derived from crosses with Hope, Pentad durum, and the Kenya wheats are resistant to stem rust but are not included in the table since they probably contain no new factors for resistance. A number of other varieties of unknown parentage that were not grown until 1939 or 1940 have given low stem rust readings. Some of these may actually be resistant, but it is probable that the light infection in the greater part of them can be attributed to early maturity, which enabled them to escape severe infection. Among these was the variety Criollo, and P. I. numbers of the other varieties with possible resistance are as follows: 124321, 124330, 124357, 124371, 124495, 124496, 124497, 124736, 124737, 124738, 124739, 124740, 124742, 124743, 124744, 124819, 50386 (C. I. 8129), 58795 (C. I. 7877), 59284 (C. I. 8156, 8159, 8160), 60387 (C. I. 8141, 8142), 60599 (C. I. 7905), 60600 (C. I. 7909, 7914), 60601 (C. I. 7922), 60604 (C. I. 7931), 60606 (C. I. 7947), 60608 (C. I. 7952), 60610 (C. I. 7967), 60611 (C. I. 7974), 60613 (C. I. 7985), 60617 (C. I. 7996, 7997, 7998), 60621 (C. I. 8077), 60623 (C. I. 8082), 60624 (C. I. 8092).

REACTIONS TO LEAF RUST

Heavy early infection with stem rust on the leaves of susceptible varieties often so seriously interfered with leaf rust readings that reliable data could not be obtained. Consequently, leaf rust reactions are presented only for the 43 *vulgare* wheats that were found to be resistant to stem rust, and the various check varieties. These data are given in table 2.

Table 2.—*Reaction to leaf rust of the 43 foreign varieties of vulgare wheat that gave lower stem rust readings than the Kota check variety*

[S=susceptible; HS=highly susceptible; R=resistant; SR=semiresistant; HR=highly resistant]

Variety or strain	P. I. No.	Other designation	Leaf rust or host response						
			College Station						Weslaco 1940
			1937	1938	1939	1940	Average, 1938–40	Rank	
			Percent	*Percent*	*Percent*	*Percent*	*Percent*		
Fronteira	103832	C. I. 12019	0	0	0	0	0	1	HR
Frondoso	106504	C. I. 12078	(1)	0	0	0	0	1	HR
Hope (check)		C. I. 8178	(1)	0	0	0	0	1	HR
M 12–32	103831		0	0	0	(1)	.2	2	R
Renacimiento		C. I. 12002	(1)	(1)	0	0	.2	2	HR
Surpresa	103833		(1)	0	(1)	0	.2	2	HR
Iumillo (check)		C. I. 1736	(1)	0	(1)	(1)	.3	3	R
Vencedor	104139	SF12708		(1)	(1)	0	.3	3	HR
Portugal 90	116231	C7921		(1)	5	0	1.8	4	R
Uruguay	116234	C10835		(1)	5	0	1.8	4	R
El Milagro	116015			(1)	5	(1)	2.0	5	HR
Uruguay 386	116326	C10838		(1)	(1)	5	2.0	5	SR
Portugal 65	116230	C7897		5	5	0	3.3	6	SR
Minor	117496	C9142		5	5	0	3.3	6	SR
Kota × Webster (check)		H151	5	5	5	(1)	3.5	7	SR
Do		H231	5	5	5	(1)	3.5	7	SR
Uruguay 392	116328	C10837		(1)	5	5	3.5	7	R
Argentine	116223	C9656		(1)	5	10	5.2	8	HR
Vernal emmer (check)		C. I. 2975	15	10	5	5	6.7	9	S
Bladette de Besplas	103528	C6148	25	5	15	(1)	6.8	10	R
Marquis (check)		C. I. 3641		15	10	5	10.0	11	S
Triunfo	104138	SF12709	30	15	15	0	10.0	11	S
Gelou		C. I. 12001	(1)	5	25	(1)	10.2	12	S
Trigo Rojo	93337		25	5	25	(1)	10.2	12	S
Argentine K40	116297	C9658		25	5	5	11.7	13	SR
Kenya	118903	C10865		15	15	5	11.7	13	SR
Do	118904	C10866		15	10	10	11.7	13	S
Varonne	116236	C6146		25	10	0	11.7	13	S
Kenya	117527	C10854		10	25	(1)	11.8	14	S
San Martin	104137	SF12706	30	10	25	(1)	11.8	14	S
Kenya × Gular	117642	5939		25	10	5	13.3	15	S
Greek 18	116226	C7142		25	15	5	15.0	16	S
Kenya × Florence × Dundee	117782	264D		25	20	(1)	15.2	17	S
Kenya	118901	C10862		15	10	25	16.7	18	S
Do	92475	K.2R.5(L.2)	40	25	25	(1)	16.8	19	S
Kenya crossbred	103540	C6042	25	25	25	(1)	16.8	19	HS
Kenya × Florence × Dundee	117786	5130		25	25	(1)	16.8	19	S
Kenya	117767	C9724		25	5	25	18.3	20	S
Do	117771	C10857		25	25	10	20.0	21	S
Do	117528	C10856		10	50	(1)	20.2	22	S
Do	117529	C10863		10	50	(1)	20.2	22	S
Do	117768	C9906		25	25	15	21.7	23	S
Kenya × Gular	117641	4913		30	25	10	21.7	23	S
Kenya	117769	C9967		25	25	25	25.0	24	S
Kenya crossbred	103539	C6040	50	25	40	10	25.0	24	S
Argentine K33	116222	C9655		50	35	10	31.7	25	S
Greek 10	116227	C7135		40	50	10	33.3	26	S
Gasta (check)		C. I. 11398		65	40	5	36.7	27	S
McMurachy selection		RL1313		40	40	35	38.3	28	HS
Kota (check)		C. I. 5878		60	35	25	40.0	29	HS
Kenya	117526	C9968		50	50	25	41.7	30	S
Thatcher (check)		C. I. 10003	25	80	35	10	41.7	30	S

[1] Trace; estimated at 0.5 in computing averages.

Several of these varieties, including Fronteira, Frondoso, Surpresa, M 12–32, Renacimiento, and the Hope check, showed marked resistance to leaf rust, whereas most of the Kenya wheats were very susceptible. The complete freedom of Hope wheat from leaf rust in all years except 1937 is surprising, since this variety is not usually entirely free from leaf rust in the spring wheat area. The complete susceptibility of Vernal emmer at Weslaco in 1940 is equally surprising,

TABLE 3.—*Some characteristics of the 43 rust-resistant wheats, tabulated for the guidance of breeders in selecting parental material*

[Under glume characters, G=glabrous; P=pubescent; SP=slightly pubescent; B=brown; W=white; K=strong keel]

Variety or strain[1]	P. I. No.	Other designation	Probable place of origin	Spike characters	Glume characters	Kernel characters		
						Texture	Color	Shape
Kenya	92475	K. 2R. 5 (L. 2)	Kenya	Apically awned, fusiform	G, B	Hard	Red	Semilong.
Trigo Rojo	93337		Spain	Awned, fusiform	G, W	do	do	Short.
Bladette de Besplas	103528	C6148	Australia	Awned, oblong	G, B	do	do	Do.
Kenya crossbred	103539	C6040	Kenya	Awnless, oblong	G, B	do	White	Long.
Do	103540	C6042	do	Awned and awnless, fusiform	G, W	do	Red	Short.
M 12-32	103831		Brazil	Awned, oblong	G, W	do	do	Long.
Fronteira	103832	C. I. 12019	do	do	G, B	Soft	do	Do.
Surpresa	103833		do	do	G, W	do	do	Do.
San Martin	104137	SF12706	Argentina	Awned, clavate	G, B	Hard	do	Short.
Triunfo	104138	SF12709	do	Awned, oblong	G, W	do	do	Do.
Vencedor	117506	SF12708	do	Awned, fusiform	G, W, K	Soft	do	Semilong.
Frondoso	106504	C. I. 12078	Brazil	Awned, oblong	G, B	do	do	Long.
El Milagro	116015		Argentina	Awned, fusiform	G, W, K	Hard	do	Short.
Argentine K33	116222	C9655	do	Awnless, oblong	G, W	Soft	White	Semilong.
Argentine	116223	C9656	do	do	G, W, K	do	Red	Short.
Greek 18	116226	C7142	Greece	Awned, clavate	G, B	Hard	do	Do.
Greek 10	116227	C7135	do	Awned, oblong	G, W	Soft	do	Semilong.
Portugal 65	116230	C7897	Portugal	Awned, fusiform	G, W	Hard	do	Do.
Portugal 90	116231	C7921	do	Awned, oblong	G, W	do	do	Short.
Uruguay	116234	C10835	Uruguay	do	G, W	Soft	White	Do.
Varonne	116236	C6146	Australia	Awnless, oblong	G, W	do	Red	Semilong.
Argentine K40	116297	C9658	Argentina	Awned, oblong	G, W, K	do	do	Short.
Uruguay 386	116326	C10838	Uruguay	do	G, W, K	do	White	Do.
Uruguay 392	117504	C10837	do	do	G, W	do	do	Do.
Minor	117496	C9142	Australia	do	G, W	Hard	do	Do.
Kenya	117526	C9968	Kenya	Apically awned, elliptical	G, W	do	Red	Do.
Do	117527	C10854	do	Awnletted, fusiform	G, B	Soft	White	Do.
Do	117528	C10856	do	Awnletted, oblong	G, B	do	do	Do.
Do	117529	C10863	do	Apically awned, fusiform	G, B	do	do	Do.
Kenya × Gular	117641	4913	Australia	Apically awned, oblong	G, B	Hard	do	Do.
Do	117642	5935	do	do	G, W	do	do	Short, plump.
Kenya	117767	C9724	Kenya	do	G, B	do	Red	Semilong.
Do	117768	C9906	do	Awnless, fusiform	G, B	do	do	Short.
Do	117769	C9967	do	Awned, oblong	G, B	Soft	do	Semilong.
Do	117771	C10857	do	Apically awned, oblong	G, W	Hard	White	Short.
Kenya × Florence × Dundee	117782	2640	Australia	do	G, B	do	do	Short, plump.
Do	117786	5130	do	do	G, B	do	do	Do.
Kenya	118901	C10862	Kenya	do	G, W	Soft	do	Semilong.
Do	118903	C10865	do	Apically awned, clavate	G, W	Hard	do	Do.
Do	118904	C10866	do	Apically awned, oblong	SP, W	do	do	Short.

Gelou		C. I. 12001	Uruguay	do	G, W	do	Red	Do.
Renacimiento		C. I. 12002	do	Awned, fusiform	G, B	do	do	Do.
McMurachy selection		RL1313	Canada	Apically awned, elliptical	G, W	do	do	Do.
Kota (check)		C. I. 5878	U. S. S. R	Awned, fusiform	G, W	do	do	Do.
Kota × Webster (check)		H151	S. Dak.[2]	do	G, W	do	do	Do.
Do		H231	do[2]	do	G, W	do	do	Do.
Vernal emmer (check)		C. I. 2975	Switzerland	Awned, oblong	G, W	do	do	Semilong.
Thatcher (check)		C. I. 10003	Minn.[2]	Apically awned, oblong	G, W	do	do	Short.
Iumillo (check)		C. I. 1736	Italy	Awned, oblong	G, W	do	do	Do.
Hope (check)		C. I. 8178	S. Dak.[2]	Awned, fusiform	G, W	do	do	Do.
Marquis (check)		C. I. 3641	Canada	Apically awned, fusiform	G, W	do	do	Do.
Gasta (check)		C. I. 11398	Georgia[2]	do	G, W	Soft	do	Do.

[1] All varieties have a spring habit of growth except Varonne and Gasta, which have an intermediate growth habit.

[2] U. S. A.

since this variety is usually highly resistant under field conditions in the spring wheat area. Furthermore, the factors for resistance in Hope and Vernal emmer have heretofore been considered as being closely related since Hope is believed to have inherited its resistance from Yaroslav emmer, which is apparently identical with the Vernal variety in morphologic characters and resistance to rust.

The physiologic races of leaf rust present in the different years are not known except for 1939 and 1940. In 1939, races 9, 13, 41, 50, and 105 were identified by C. O. Johnston, of Manhattan, Kans., from material collected at College Station, Tex. In 1940, races 3, 9, 20, 28, 31, 44, 58, and 105 were identified from collections made at College Station; races 11, 13, 28, and 54 from Angleton; and races 9 and 28 from Weslaco.

Use of New Varieties as Parental Material

The experiments reported in this circular were undertaken primarily to assist breeders in developing rust-resistant varieties of wheat adapted to the wide range of conditions existing in the United States. The various rust-resistant varieties that have come to light as a result of these investigations are of many different types. Many of them naturally have other desirable characteristics besides resistance to the two rusts that commonly occur in this country, and also some undesirable characteristics.

It is obvious that a breeder attempting to breed rust resistance into soft white spring wheats would be wise to select as a parent, a rust-resistant variety of the same class, other things being equal. An attempt was made, therefore, to evaluate partially these new rust-resistant varieties for specific breeding problems. Certain important characteristics of each variety are presented in table 3 as a guide to selecting varieties to obtain characters other than rust resistance.

The following varieties always gave resistant reactions to stem rust and were consistently low in stem rust percentage readings: Trigo Rojo, M 12–32, Fronteira, Surpresa, Frondoso, Argentine, Argentine K33, Portugal 65, Portugal 90, Uruguay (P. I. 116234), Argentine K40, Uruguay 386, Uruguay 392, Minor, Renacimiento, and the varieties from Kenya and most of their derivatives. Among the wheats of this group, the Kenya varieties and most of their derivatives, although very susceptible to leaf rust, are outstanding for their early resistance to stem rust and for their tendency to make rapid top growth and come into head in February while the day length is still short. These characteristics should make the Kenya wheats of special value in breeding stem rust-resistant varieties for tropical and subtropical regions. Also the possibility of combining their early resistance with the mature plant resistance from Hope wheat to obtain resistance throughout the growth cycle appears to be worth investigating.

The following classes are found among the Kenya wheats: Hard red spring, soft red spring, hard white spring, and soft white spring. Although all of them have the typical growth habit of the true spring wheats, they are capable, when fall-sown, of making rapid erect growth during the short-day winter season of the subtropics. They are "winter-growing" varieties with a so-called spring-type growth habit.

The following varieties were highly resistant to leaf rust: M 12–32, Fronteira, Surpresa, Vencedor, Frondoso, El Milagro, Portugal 65, Portugal 90, Uruguay (P. I. 116234), Uruguay 386, Uruguay 392, Minor, and Renacimiento. Within this group of wheats all, except Vencedor and El Milagro, also have shown consistently high resistance to stem rust.

In tests conducted by C. O. Johnston,[5] the variety Renacimiento has also proved resistant to the hessian fly. These characteristics, together with its short, hard red kernel, should make this variety of special value in the breeding of good-quality, rust-resistant hard red winter wheats, especially for the southern part of the winter wheat belt of the United States, where resistance to the hessian fly and to both rusts is of great importance.

The varieties Fronteira, Surpresa, and Frondoso have soft red kernels and should be of special value in the breeding of both soft red winter wheats and soft red spring wheats. Portugal 65 and Portugal 90 are very early maturing varieties with hard red kernels, which may have special value in the breeding of hard red spring wheats for the far north. The three Uruguay varieties have soft white kernels, which should make them of value in the breeding of soft white varieties for the Pacific Northwest. Minor has hard white kernels, which suggests its possible value in the breeding of hard white wheats. All varieties listed in table 3 except Varonne (C. I. 6146) and Gasta (C. I. 11398) have a spring growth habit.

The following varieties have rigid, strongly keeled glumes that make them of promise in breeding for nonshattering qualities: Vencedor, El Milagro, Argentine (P. I. 116223), Argentine K40, and Uruguay 386. Of these, Vencedor, Argentine (P. I. 116223), and Argentine K40 are soft red spring wheats; Uruguay 386 is a soft white spring; and El Milagro is a hard red spring variety. All these varieties appear to be of value as parental material within their respective classes.

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